4. Research Plan

a. Background

Problem Statement

The Wisconsin Department of Transportation (WisDOT) is deploying the AASHTOWare Pavement ME Design software (ME-Design) for pavement structural design. As part of this pavement design procedure, assumptions about the long-term strength of the virgin base aggregate will influence the final pavement thickness design. The department performs over 1,500 borings per year as part of the soil/pavement design process. These borings are used to evaluate the existing soil and pavement materials for incorporation into the pavement design process. However, it has often been observed during construction that the virgin base aggregates have degraded since original placement. WisDOT has hypothesized three potential causes:

1. Individual aggregate chemical and physical breakdown/deterioration
2. Freeze/thaw action
3. Infiltration of subgrade materials

The purpose of this research is to investigate potential degradation of virgin aggregate bases, investigate/document strength reductions over time, and evaluate the likely causes for both. This information will be used for current and future local calibration of the ME Design software.

Significance of Unbound Base Layers for Pavement Performance

Unbound base layers function by supporting traffic loads from the asphalt concrete surface layer and dissipating and transferring such loads to the underlying pavement layer or subgrade. Therefore, the unbound aggregate layers comprise a significant intermediate component in pavement stability and performance.

Performance of unbound aggregate materials in base course layers depends on the characteristics/properties of the individual aggregate particles and the interaction behavior of groups of particles associated/aggregated in a matrix (e.g., in base course layer). The importance of the individual particle properties comes from its influence on the group behavior within the matrix. Particle properties include (1) particle size, (2) particle shape, (3) particle texture, (4) particle angularity, (5) particle durability, (6) specific gravity, (7) absorption, (8) particle toughness, and (9) particle mineralogical composition. Properties of aggregate within matrix (such as base layer) include: (1) shear strength, (2) stiffness, (3) density, (4) resistance to permanent deformation, (5) permeability, and (6) frost susceptibility (Saeed et al. 2001).

The individual characteristics of aggregate particles (e.g., shape, angularity, texture) define their ability for interlocking behavior in a packed matrix, such as in base course layers, to provide the desirable structural stability to support traffic loads. Proper construction of aggregate base layers will produce densely packed materials with good interlocking among the particles, leading to increased shear strength and stability and decreased permanent deformation as the void space between particles is minimized. A lack of stability in the base course layers results in the lateral movement of aggregates, thereby causing pavement distress (Barksdale, 2001).

The particle and matrix properties of aggregate particles and unbound base layers influence the performance of flexible pavements. Within the context of aggregate particle durability and strength, the pavements are expected to perform very well; however, poor performance of base layers due to weak/deteriorated aggregate particles can lead to poor pavement performance and early distress and deterioration. Flexible pavement distresses such as fatigue cracking, rutting/corrugations, depressions, and frost heave can be attributed to the poor performance of unbound aggregate base course layers (Saeed et al., 2001).

Saeed et al. (2001) discussed the distresses that are attributed to the poor performance of unbound base course layers. These distresses include: <u>(a) Fatigue cracking</u> occurs in areas subjected to repeated traffic loading. Cracking starts as fine, longitudinal hairline cracks running parallel to one another in the wheel path. High flexibility in the aggregate base allows excessive bending strains in the asphalt concrete surface. The same result can also be caused by inadequate thickness of the aggregate base. Changes in the base properties with time can render the base inadequate to support loads. The contributing factors to fatigue cracking related to the base layer are: (1) low elastic modulus of the base layer, (2) improper gradation, (3) high fines content, (4) high moisture levels, (5) lack of adequate particle angularity and surface texture (poor interlocking), and (6) degradation under repeated loads and freeze-thaw cycling. <u>(b) Rutting</u> results from permanent deformation in one or more layers or at the subgrade, usually caused by consolidation and/or lateral movement of the material due to load. Rutting appears as a longitudinal surface depression in the wheel path and may not be noticeable, except during and following rainfall. Inadequate shear strength in the base allows lateral displacement of particles with applications of wheel loads, causing a decrease in the base layer thickness in the wheel path. Inadequate density causes settlement of the base. The contributing factors to rutting are: (1) low shear strength of aggregate base, (2) inadequate compaction, as illustrated by low density, (3) improper gradation, (4) high fines content, (5) high moisture levels, (6) lack of adequate particle angularity and surface texture, and (7) degradation under repeated loads and freeze-thaw cycling. (c) Frost heave appears as an upward bulge in the pavement surface and may be accompanied by surface cracking, including alligator cracking with resulting potholes. Ice lenses are created within the base/subbase during freezing temperatures as moisture is pulled from below by capillary action. During spring thaw, large quantities of water are released from the frozen zone, which can include all unbound materials. The contributing factors to this distress are: (1) freezing temperatures, (2) source of water, (3) and permeability of material high enough to allow free moisture movement to the freezing zone.

Characterization of Aggregate Particle Properties

The aggregates particle properties/characteristics that are important for the performance of aggregate layers and how they are determined by laboratory tests are discussed here in detail. The aggregate handbook (Barksdale, 2001) provides a detailed description of aggregate properties, as well as quantification tests. NCHRP Project 4-23, "Performance-Related Tests of Aggregates for Use in Unbound Pavement Layers (NCHRP Report 453)," summarized the most important tests that relate to the performance of aggregates in unbound pavement layers. These properties are: gradation (particle size distribution), particle shape, particle texture, toughness, particle strength particle stiffness, permeability, and frost susceptibility.

Various test methods are available to evaluate the properties of unbound granular materials and how these properties influence pavement performance in terms of distresses, structural stability, and ride quality. Table 2.2 describes the relationship between aggregate properties/test and pavement-performance parameters.

Table 1: Relationship between aggregate properties and pavement-performance parameters (after Saeed et al. 2001)

Pavement Type	Performance Parameter	Related Aggregate Property	Test Parameters that May Relate to Performance
Flexible	Fatigue Cracking	Stiffness	Resilient modulus, Poisson's ratio, gradation, fines content, particle angularity and surface texture, frost susceptibility, degradation of particles, density
	Rutting Corrugations	Shear Strength	Failure stress, angle of internal friction, cohesion, gradation, fines content, particle geometrics (texture, shape, angularity), density, moisture effects
	Fatigue Cracking, Rutting, Corrugations	Toughness	Particle strength, particle degradation, particle size, gradation, high fines
		Durability	Particle deterioration, strength loss
		Frost Susceptibility	Permeability, gradation, percent minus 0.02 mm size, density, fines type
		Permeability	Gradation, fines content, density

b. Research Objectives

The purpose of this research is to investigate potential degradation of virgin aggregate bases, investigate and document strength reductions over time, and evaluate the likely causes for both. This information will be used for current and future local calibration of the ME Design software. Aggregate degradation is defined as the breakdown of an aggregate into smaller particles (Barksdale 1991).

c. Research Approach

i. Work Plan/Experimental Design

Task 1: Conduct Literature Search and Review

The research team will conduct a comprehensive literature search and review to obtain information and data on the evaluation of long-term degradation and strength characteristics of in-situ virgin base aggregates under HMA pavements and their influence on performance of HMA pavements. Publications (technical papers, reports, thesis, etc.) on this subject will be collected, reviewed, analyzed and synthesized. The following studies/documents are identified and will be included in the literature review:

1. NCHRP Project 01-53 (currently pending): ***Proposed Enhancements to Pavement ME Design: Improved Consideration of the Influence of Subgrade and Unbound Layers on Pavement Performance.***
2. NCHRP Project 10-84 (currently active): ***Modulus-Based Construction Specification for Compaction of Earthwork and Unbound Aggregate.***
3. WHRP study 0092-02-01: ***Determination of Influences on Support Strength of Crushed Aggregate Base Course Due to Gradational, Regional, and Source Variations.***
4. WHRP Study 0092-10-08: "***Investigation of Testing Methods to Determine Long-Term Durability of Wisconsin Aggregates***," [conducted by the proposing team Tabatabai and Titi].

5. WHRP study 0092-11-02: "***Base Compaction Specification Feasibility Analysis***," [conducted by the proposing team Titi, Tabatabai and Faheem].
6. WHRP Study 0092-02-03: ***Investigation of Testing Methods to Determine Long-Term Durability of Wisconsin Aggregate Resources Including Natural Materials, Industrial Byproducts, and Recycled/Reclaimed Materials.***
7. NCHRP Synthesis 445: ***Practices for Unbound Aggregate Pavement Layers.***
8. NCHRP Synthesis 382: ***Estimating Stiffness of Subgrade and Unbound Materials for Pavement Design.***

Task 2: Conduct Survey of State DOTs in the U.S. and MOTs in Canada

The research team will conduct a survey on methods and practices of state highway agencies in the U.S. and Canada pertaining to methods of evaluating the long-term degradation and strength characteristics of in-situ virgin base aggregates under HMA pavements and their influence on performance of HMA pavements. The research team will design and distribute this survey to all 50 State DOTs in the country and to the Ministries of Transportation (MOTs) in Canada. The survey will be designed by the research team and approved by the TOC (or the project oversight committee) before distribution to assure the benefit of the survey. The survey will include question on if and how other state highway agencies account for loss of base aggregate strength over time in their pavement designs. The research team has conducted national surveys for research projects including the WHRP base compaction specifications study.

Task 3: Conduct Comprehensive Field and Laboratory Testing Program on Selected Existing HMA Pavements

The research team will develop and implement a work plan that will achieve the objective of this research. The work plan is described here. The research team will consult and obtain feedback from the TOC to ensure maximum benefits for the research outcome.

Subtask 3.1: Identify, Select and Develop Database of Existing HMA Pavements Selected for Field/Laboratory Testing and Evaluation

The research team will identify 25 roadway sections of existing HMA pavements. These project sites will be identified in a coordinated effort with the TOC/POC. The research team includes Scot Schwandt, the former Engineering Director of WAPA who has excellent familiarity of existing HMA pavement in Wisconsin and will lead this effort.

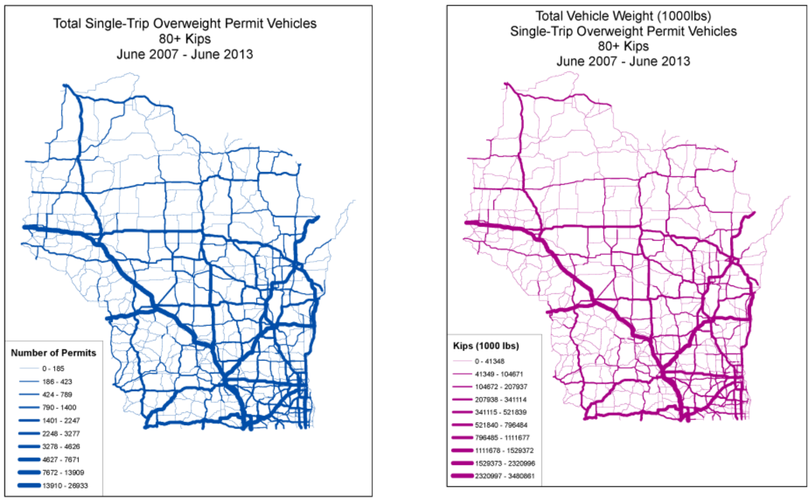
The following criteria will be used to identify and select project sites for this study:

1. *Geographical Location:*
    a. To include virgin aggregate bases built on top various common subgrade soils of Wisconsin.
    b. To include various types of virgin aggregate materials based on source location (we will thoroughly review WHRP study 0092-02-01: Determination of Influences on Support Strength of Crushed Aggregate Base Course Due to Gradational, Regional, and Source Variations and WHRP Study 0092-10-08: "Investigation of Testing Methods to Determine Long-Term Durability of Wisconsin Aggregates).
    c. To include areas with various Freeze-Thaw conditions such as northern Wisconsin versus Southern Wisconsin.
2. Traffic Loading: To include roadways with various traffic loads. The research team will use WisDOT published traffic data for this item. In addition, the PI conducted research on Wisconsin overload truck permits that includes analysis of data for the past five years. Figure 1 shows the distribution of total permit numbers and total truck weights for single trip overweight permit trucks in Wisconsin between June 2007 and June 2013.The results of the study will also help in identifying routes with heavy truck traffic for selection of candidate project sites.
3. Pavement Age and Suspected Level of Base Deterioration /Degradation*:* To include HMA pavements with various surface conditions that are attributed to performance deterioration of virgin base aggregate. It is expected that the research team and TOC/POC will look into project sites that are 10 years of age and older.
4. It expected that the selected projects have 'good' (or available) construction material records. Construction Project Materials records will be collected from WisDOT archives including MTS system.

Once these projects are identified and selected for field and laboratory study, the research team will develop a database that includes historical information and data pertaining to these project sites. The database will include information collected from WisDOT archives such as Pavement Inventory File (PIF) and Quality Management Program (QMP) data:

1. As-built plans that include pavement layer thicknesses.
2. Base aggregate specifications used, type of the aggregate, source of the aggregate, historical as-built construction aggregate material testing (gradation, wear and soundness) and any other available useful information (this information will be verified during field study e.g., base layer thickness).

3. Available information about materials used in other pavement layers, specifications, acceptance reports, and field/laboratory tests and results (such as field density of HMA).
4. Review of project diaries for pavement performance data during construction including notes and any other important information/observations noted during construction of aggregate base layer and other layers of the pavement and subgrade. Diaries will have useful information on the weather, equipment used, and notes if the base material deformed (base yield under the paver) during HMA layer construction, etc.
5. Historical information of pavement performance such as Pavement Condition Index (PCI), Pavement Distress Index (PDI), International Roughness Index (IRI) and Profile Index (PI). The research team is aware that WisDOT switched specification and that PCI, PDI, IRI, and PI may all not be available for all projects.



(a) Number of Permits (b) Total truck weight

Figure 1: Distribution of total permit numbers and total truck weights for single trip overweight permit trucks in Wisconsin between June 2007 and June 2013 (Titi, et al. 2014 - presented at TRB 2014).

<u>Subtask 3.2: Conduct Field Testing Program on Existing HMA Pavements Selected</u>

The research will perform the following field testing program on the HMA pavements selected in Subtask 3.1. The following is a proposed testing program. As stated in the RFP, the final matrix of test locations and activities will need to be agreed to by both WisDOT and the research team.

1. <u>Perform pavement condition survey</u>: For each of the 25 selected pavements, one-mile long section of pavement will be identified by the research team. This 1-mile section will include areas of distressed pavement surface and areas of non-distressed pavement surface. The research team will conduct a windshield survey to determine two test sections which include problem areas (failure zones) as well as good areas. Each test section will be 150 ft. long. Detailed visual pavement distress surveys will be conducted to quantify various distresses based on type, amount, and severity level. The Pavement Condition Index (PCI) will then be calculated for each section.

2. <u>Perform Falling Weight Deflectometer (FWD) testing and analyze test results</u>: The FWD test will be conducted by WisDOT and the research team will analyze the results in order to back-calculate the pavement layer moduli. UWM owns a licensed copy of ERI software designed for analysis of KUAB FWD tests (KUAB owned by WisDOT). The FWD testing will be conducted according the following plan:
    a. FWD will be conducted every 100-ft for the length of the1-mile section on the outside wheel path and on the on the centerline of the lane, as shown in Figure 2.
    b. For a length of 100-ft, the FWD will be conducted on the outside wheel path, lane centerline, and the inside wheel path every 10-ft distance according to Figure 3.

Analyses will be conducted on the FWD test results using a backcalculation algorithm (ERI Inc. software) with inputs on pavement layers thicknesses (from project plans and field measurements/verifications) to calculate the base layer modulus, pavement structural number, subgrade soil modulus, pavement layer deflection, etc.

The FWD test configuration will test a long section of each selected pavement (1-mile) so that variability in pavement performance is accounted for, i.e., testing good performing areas as well as distressed areas will provide information needed for analysis and comparisons. Selecting 100-ft section with 10-ft test spacing will provide a contour map of the layer moduli that will be useful for the analysis of the aggregate base modulus variability that could be attributed to aggregate degradation and deterioration. The research team used this method in the analysis of existing pavement for the WHRP base compaction study as shown in Figure 4.

3. <u>Coring of pavement surface and drilling borehole</u>: Wisconsin DOT will core locations of good pavement surfaces as well as distressed pavement surfaces at six locations at each selected project site, as shown in Figure 5. The locations include “good area” at the centerline of the lane and “distressed areas” at the outside wheel path along the transverse location to provide data that allow for comparing aggregate base degradation due to traffic loading. Selecting “distressed areas” for coring and testing at both the center line and wheel path will provide data for comparing the impact of climate conditions (freeze-thaw) and aggregate type on the degradation of base aggregate. The coring will allow the research team to retrieve base aggregate materials for laboratory tests, measure the different pavement layer thickness, verify the information provided by the as-built plans, and retrieve subgrade soil samples for identification/classification of subgrade soil type. If the project selected is under state of rehabilitation, then removing larger area of the pavement surface layer would be preferred as it allows the research team to acquire large aggregate material sample needed for laboratory testing. The research team will fill the holes with asphalt mix if needed.

4. <u>Perform Dynamic Cone Penetration Test (DCP) and analyze results:</u> During the coring described in item 2 above, the research team will perform DCP test starting at the top of the aggregate base layer (once the HMA surface layer is cored), i.e., the DCP will start before disturbing and sampling the base and subgrade. The DCP will be driven through the base layer and subgrade. Test results will be analyzed by the research team. Locations of DCP testing are shown in Figure 5.

5. <u>Perform pavement surface profile measurements (suggested)</u>: the RFP did not include profile measurements using a WisDOT inertial profilometer; however, the research team recommends that this field work be conducted by WisDOT. MEPDG produces the results of pavement performance in terms of pavement distress and ride quality (IRI) with time. If inertial profilometer testing is conducted, the research team will have one more criterion (i.e., the ride quality IRI) to evaluate the pavement performance, which will benefit the study. In addition, the existing historical information on PCI and IRI obtained from PIF will help in establishing the performance of these measures with time. If agreed upon, the research team will provide detailed plans for the 1-mile test section using WisDOT inertial profiles or a smaller test section using the walk-behind profiler (or any available profiler).

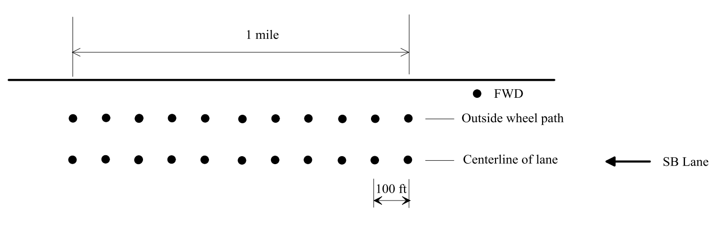


Figure 2: Proposed FWD test pattern at outside wheel path and lane centerline for 1-mile test section.

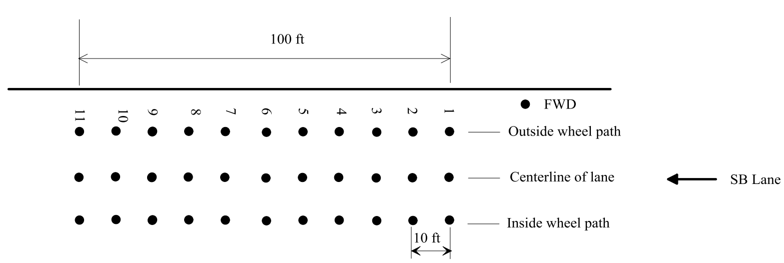


Figure 3: Proposed FWD test pattern for 100-ft test section.

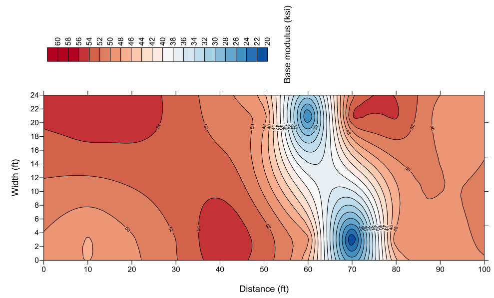


Figure 4: Contour of backcalculated elastic modulus for the aggregate base layer for STH 40, Rusk County (Titi et al. 2013).

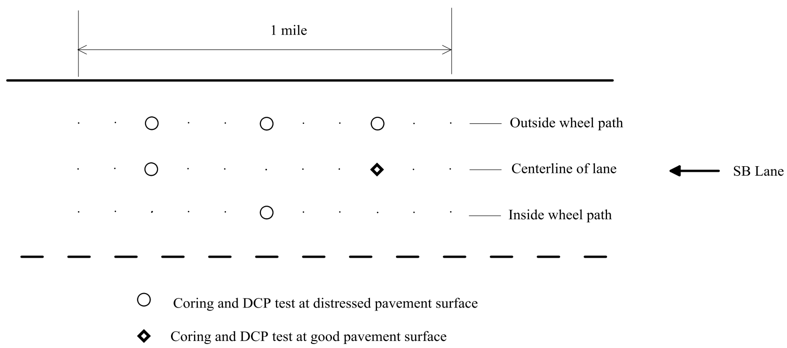


Figure 5: Proposed coring, aggregate and subgrade sampling, and DCP test locations at distressed and good pavement surface areas within the 1-mile test section.

Subtask 3.3: Conduct Laboratory Testing Program Aggregate and Subgrade Soil Collected from the Existing HMA Pavements Selected

The research team will acquire representative base aggregate materials for laboratory tests during the "Coring of pavement surface and drilling borehole" item described in Subtask 3.2. In addition, subgrade materials below the aggregate will be collected for laboratory testing:

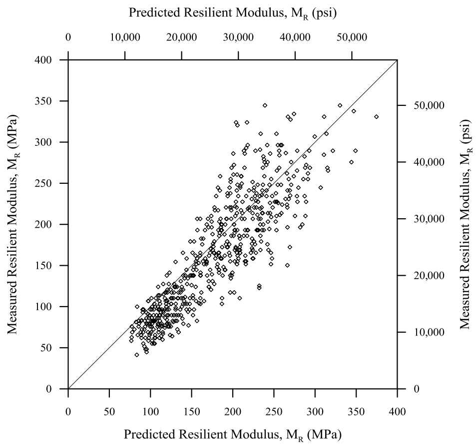
1. Conduct Particle Size Analysis on Collected Base Aggregate: Obtain grain size distribution (according to WisDOT requirements) of the collected base aggregate and calculate the various parameters associated with the test such as coefficient of uniformity (C_u), curvature coefficient (C_c), effective size (D_{10}), etc. Analyses of particle size distributions and comparisons of aggregates obtained from distressed versus good pavement areas will provide information about potential aggregate degradation/deterioration.
2. Perform Aggregate Absorption Test: The test will be conducted on the collected base aggregate materials. WHRP study 0092-10-08 conducted by the research team showed that Wisconsin aggregate durability correlated well with aggregate absorption. Therefore, absorption will be useful in evaluating aggregate durability and potential degradation.
3. Perform Repeated Load Triaxial Test: If the research team is able to acquire enough volume of base aggregate materials during coring/borehole/excavating, AASHTO T307 will be conducted for a limited number of projects with aggregates showing potential degradation (approximately five projects). Resilient modulus values of aggregates from distressed pavement areas will be compared with values from good pavement areas and compared with base layer moduli from FWD. This will provide data needed for the MEPDG pavement performance analysis using AASHTOWare MEPDG. For these aggregates, other laboratory tests may be conducted since results are needed for the resilient modulus prediction models, such as the compaction test (AASHTO T99).
4. Perform California Bearing Ratio (CBR) Test: CBR will be conducted on the limited number of aggregate materials collected from the five projects in item 3 above (Perform Repeated Load Triaxial Test). This test will allow the research team to compare strength of aggregates obtained from distressed and good areas. Comparisons of test results will also be made with results of the DCP test.
5. Conduct Particle Size Analysis and Consistency Limits of Subgrade Soils: Identify soil types and classify subgrade soils below each aggregate test location. This is needed to investigate potential pumping of fines into base layers and is also needed as input for the AASHTOWare MEPDG analysis of pavement performance. Such data can also be used to estimate the resilient modulus

of subgrade soils using models developed the WHRP resilient modulus study and to compare results with subgrade modulus obtained from FWD testing.

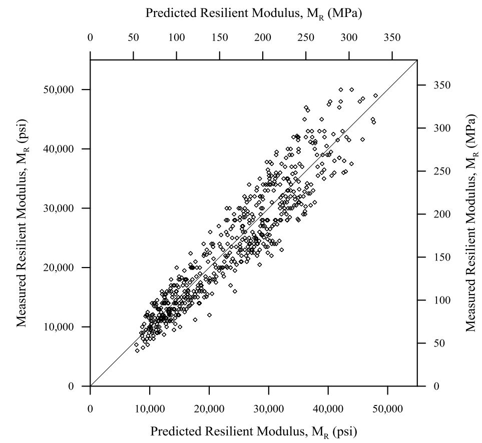
Task 4: Comprehensive Analysis of Data/Information Collected in Previous Tasks

The research team will conduct comprehensive analyses on the results of field and laboratory testing for the purpose of achieving the research objectives. The analyses will include but not limited to:

1. Analyses of FWD test results and backcalculated pavement layer and subgrade soil moduli. Comparisons of base layer modulus values evaluated at good and distressed areas will be conducted and used (with other supporting results) to assess the possibility of base aggregate degradation and deterioration due to traffic, climatic, and aggregate properties/type. Comparisons of base layer modulus values obtained from FWD tests and resilient modulus obtained from the repeated load triaxial tests on limited number of samples will be performed. This step will also establish pavement layer moduli as inputs for the AASHTOWare MEPDG analysis of the performance of all investigated pavements.
2. Analysis of the DCP test results on the aggregate base layer and subgrade soils. This analysis will also be used to predict the variation of base layer and subgrade soil strength with depth using correlations between penetration rate index and CBR. The research team used a similar analysis to investigate base layer variability along the depth of various constructed base layers in Wisconsin. Analyses and comparison of CBR test results with CBR predicted from DCP. These results in addition to other test results will be correlated to potential aggregate degradation/deterioration.
3. Analysis of pavement surface visual distress surveys conducted on the investigated pavements. The Pavement Conditions Index (PCI) will be calculated according to the ASTM standard procedure of distress quantification. Pavement conditions will be related via analysis and comparison with other supporting results to base layer performance/deterioration/degradation.
4. Analysis of particle size tests on collected base aggregate samples. Comparisons of particle size distributions of the aggregates within the same project but obtained from different locations (e.g., distressed and good areas) will be conducted. Statistical analysis will be performed to establish correlations between particle size distributions/parameters (C_c, C_u, D_{10}, etc.) to assess possible aggregate particles degradation/deterioration. Results will also be compared with the particle size distributions of the aggregate reported in the as-built documents. Titi and Matar (2013) performed comprehensive analysis on resilient modulus of base aggregates conducted in Wisconsin. Resilient modulus test results from WHRP study conducted by Omnni, Inc. and by Titi et al. were collected and analyzed. Statistical analysis was conducted on the test results and resulted in establishing MEPDG model for estimating resilient modulus of crushed virgin aggregate from basic soils parameters as shown in Table 2 (UW-Milwaukee model). Comparison of predicted and measured resilient modulus values showed acceptable level of correlation (Figure 6). This model will be used through the results of basic aggregate properties (particle size distribution, etc.) to estimate the resilient modulus of base aggregate at all test locations (distressed and good areas as well as the original aggregate properties from the as-built plans) for each project. The resulted resilient modulus values will provide information about pavement performance and base performance when comparing results and when used in the AASHTOWare MEPDG to predict pavement performance.
5. Analysis of laboratory test results on subgrade soils. This will provide information needed about soils type and potential pumping of fines into the aggregate base layer. It will also support the estimation of the resilient modulus of subgrade soils from models developed by WHRP resilient modulus study. Comparisons of resilient modulus values from prediction models and from subgrade modulus from FWD test results will be made. Comparisons of modulus values between distressed areas and good areas will provide information about the possible aggregates deterioration and contribution of the subgrade soil to this issue.
6. Establish AASHTOWare MEPGD input parameters for aggregate base layers at all investigated locations for all pavements based on field and laboratory test results and collected information from as-built plans/other sources. The PI has been using the AASHTOWare MEPGD for research for 2 years at UW-Milwaukee using a research license that was acquired by the PI. The PI also attended the AASHTOWare MEPGD training conducted by WisDOT in June 2013. Using these input parameters, pavement performance will be analyzed and comparisons will be made between pavement performance under various inputs (e.g., base layer modulus at distressed and good areas; base layer modulus of aggregate from as-built properties versus distresses/good values)



(a) Using the LTPP Crushed Stone Materials Model (LTPP Material Code 303)



(b) Using UW-Milwaukee model developed based on OMNNI data

Figure 6: Predicted versus measured resilient modulus of Wisconsin aggregate data (OMNNI data) using Crushed Stone Materials-LTPP Material Code 303 and UW-Milwaukee model.

Task 5: Reporting and Final Report

The research team will document the effort of the study on a final report in accordance with WHRP requirements in the RFP. The research team will present the results (PowerPoint presentation) to the TOC and address review comments.

Table 2: MEPDG resilient modulus model for Wisconsin virgin base aggregate and the model developed by LTPP

Model Name	Base Aggregate Resilient Modulus Prediction Model Equations
Crushed Stone Materials-LTPP Material Code 303	$k_1 = 0.7632+0.0084 (P_{3/8}) + 0.0088\ LL-0.0371\ W_{opt} -0.0001\ \gamma_{d,max}$
	$k_2= 2.2159 - 0.0016 (P_{3/8}) + 0.0008\ LL - 0.038 W_{opt} - 0.0006\ \gamma_{d,max} + 2.4x(10^{-7})(\frac{\gamma^2{}_{d,max}}{P40})$
	$k_3= -1.72 - 0.0082 LL - 0.0014\ W_{opt} + 0.0005\ \gamma_{d,max}$
UW-Milwaukee model (using OMNNI data)	$k_1 = -(179.23) - (48.18)\ W_{opt}\ (\%) - (21.195)\ P_{200}\ (\%) + (15655.34)\ D_{10}\ (in) + (966.45)\ D_{30}\ (in) - (1749.57)\ D_{60}\ (in) + (2.48)\ C_u + (22.98)\ C_c + (1.91)\ P_{3/8}\ (\%) + (6.91)\ P_{40}\ (\%) + (742.48)\ D_{85}\ (in) - (386.986)\ \frac{W_s\ (\%)}{W_{opt}\ (\%)} +$
	$Log(k_2) = -(0.85679) + (0.031876)\ W_{opt}\ (\%) + (0.0017715)\ \gamma_{d,max}\ (pcf) + (0.000271)\ \gamma_s\ (pcf) + (0.0051635)\ P_{200}\ (\%) - (1.12315)\ D_{10}\ (in) - (0.22246)\ D_{30}\ (in) + (0.37281)\ D_{60}\ (in) - (0.000739)\ C_u + (0.00008557)\ C_c + (0.00326)\ P_{3/8}\ (\%) - (0.0008311)\ P_{40}\ (\%) - (0.02326)\ W_s\ (\%) + (0.06093)\ D_{85}\ (in)$
	$k_3 = (1.47932) - (0.01065)\ W_{opt}\ (\%) - (7.15894)\ D_{10}\ (in) + (0.2209)\ D_{30}\ (in) - (0.2369)\ D_{60}\ (in) + (0.0009104)\ C_u - (0.017941)\ C_c - (0.0149)\ P_{3/8}\ (\%) - (0.000271)\ P_{40}\ (\%) - (1.01648)\ D_{85}\ (in) + (0.0000162412)(\gamma_s * \gamma_{d,max})$

$$M_R=k_1\ P_a\ [\frac{\theta}{P_a}]^{k_2}[\frac{\tau_{oct}}{P_a}+1]^{k_3}$$

ii. Expected Contribution from WisDOT Staff

1. WisDOT/TOC Staff Time: according to the RFP, the following will be provided by WisDOT:

(a) In coordination with research team, advise/help in selecting the field project sites; (b) provide guidance/approval (as required by the RFP) on the final field testing plan (c) Provide access to approximately 25 roadways for field tests; (b) Provide access to available historic information concerning aggregate material test results from the time of construction of the tested roadways, aggregate source information (if available), years of construction and access to standard specifications for those years; and (c) Provide access to traffic information.

2. **Equipment:** (a) A drill rig and crew to facilitate collection of field samples and field tests, The researcher will accommodate drill crew schedules; (b) FWD test results for the field test location sites; (c) if approved by WisDOT, the research team would like to obtain pavement surface profile measurements using an inertial profilometer (see Field Testing Program).

iii. Other Equipment and Materials:

1. Equipment: None

2. Materials: None

d. Anticipated Research Results and Implementation Plan

The findings from the research should include the following:

- The results of the field and laboratory tests.
- A summary of the potential for degradation of virgin base aggregate materials and the factors influencing this degradation.
- A comparison of the current aggregate strengths to the estimated strengths at the time of placement.
- Recommendations on the effect of degradation on the structural support capacity of virgin base aggregates, with respect to time or other investigated variables.
- A final report documenting all research findings and conclusions (8 paper copies of the final report and an electronic file)
- Recommendations for WisDOT to incorporate into MEPDG, but the actual incorporation of results will be the responsibility of WisDOT.

5. Time Requirement

A project time duration of 24 months (8 quarters) is proposed. The proposed project beginning date is August 1, 2014. Project schedules for different tasks are shown below.

Task	Year 1				Year 2			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Literature Review								
Survey								
Field and Lab Testing								
Analyses								
Report				X				

X: interim progress report

6. Budget:

Summary of Hours

INDIVIDUALS	TASKS					TOTAL HOURS
	1	**2**	**3**	**4**	**5**	
Hani Titi	10	2	114	30	20	176
Habib Tabatabi	10	30	100	10	10	160
Ahmed Faheem	10	2	150	40	20	222
Scot Schwandt	8	8	100	40	20	176
Bill Niemi	0	5	30			35
Erol Tutumuler	2	0	8	5	0	15
Graduate Student	40	30	600	60	40	770
Hourly Student	40	20	400	30	10	500
TOTALS	120	97	1502	215	120	2054

a. Itemized Budget

Table 1: Work Effort by Task

INDIVIDUALS	TASKS					Total Salaries	Fringes	Total Salaries and Fringes
	1	**2**	**3**	**4**	**5**			
Hani Titi	550	110	6273	1651	1101	$ 9,685.00	$ 3,341.33	$ 13,026.33
Habib Tabatabi	563	1688	5625	563	563	$ 9,000.00	$ 3,105.00	$ 12,105.00
Ahmed Faheem	415	83	6222	1659	830	$ 9,207.95	$ 3,176.74	$ 12,384.70
Scot Schwandt	455	455	5682	2273	1136	$ 10,000.00		$ 10,000.00
Bill Niemi	0	500	3000	0	0	$ 3,500.00		$ 3,500.00
Erol Tutumuler	200	0	800	500	0	$ 1,500.00		$ 1,500.00
Graduate Student	987	740	14805	1481	987	$ 19,000.00	$ 4,598.00	$ 23,598.00
Hourly Student	480	240	4800	360	120	$ 6,000.00	$ 246.00	$ 6,246.00
TOTALS	$ 3,649.12	$ 3,815.32	$ 47,206.84	$ 8,485.69	$ 4,735.99	$ 67,892.95	$14,467	$ 82,360.02

Table 2 Total Contract Summary by Fiscal Year						Year 1*	Year 2	TOTALS	
Total Salaries, Wages and Fringes (From Table 1)	$ 4,434.66	$ 4,653.08	$ 57,237.84	$ 10,194.73	$ 5,839.72	$41,988	$40,372	$82,360	
Sub-Contracts (Please list each subcontract seperately)									
Ahmed Faheem	558	112	8368	2231	1116	$6,000	$6,385	$ 12,384.70	
Scot Schwandt	455	455	5682	2273	1136	$5,000	$5,000	$ 10,000.00	Lump sum
Bill Niemi	0	500	3000	0	0	$2,500	$1,000	$ 3,500.00	Lump sum
Erol Tutumuler	200	0	800	500	0	$1,000	$500	$ 1,500.00	Lump sum
Subtotal	$ 1,212.41	$ 1,066.12	$ 17,849.86	$ 5,004.20	$ 2,252.10	$14,500	$12,885	$ 27,384.70	
Other Direct Costs									
Laboraory test fees	0	0	12485	0	0	$8,000	$4,485	$ 12,485.00	
Item 2								$ -	
Item 3								$ -	
Subtotal	$	$ -	$ 12,485.00	$ -	$ -	$ 8,000.00	$ 4,485.00	$ 12,485.00	
Materials & Supplies (List all items over $1000 seperately)									
Supplies for storing collected aggregate samples	0	0	500	0	0	$400	$100	$ 500.00	
Subtotal	$ -	$ -	$ 500.00		$ -	$400	$100	$ 500.00	
Travel (State number of trips and estimated cost/trip)									
*Trips to project locations during various field tests(40 trips, $200/trip)***	0	0	8000	0	0	$5,000	$3,000	$ 8,000.00	
Trips to WisDOT for project meetings	100	100	100	100	100	$300	$200	$ 500.00	
Subtotal	$ 100.00	$ 100.00	$ 8,100.00	$ 100.00	$ 100.00	$5,300	$3,200	$ 8,500.00	
Communications (Printing is required)									
Printing (8 printed final reports are required)	0	0	0	0	300	$0	$300	$ 300.00	
Literature materials	200	0	0	0	0	$200	$0	$ 200.00	
Subtotal	$ 200.00	$ -	$ -		$ 300.00	$200	$300	$ 500.00	
TOTAL DIRECT COSTS	**$ 4,734.66**	**$ 4,753.08**	**$ 78,322.84**	**$ 10,294.73**	**$ 6,239.72**	**$55,888**	**$48,457**	**$104,345**	
TOTAL INDIRECT COSTS (Provide Rate and Base)	**$710**	**$713**	**$11,748**	**$1,544**	**$936**	**$8,383**	**$7,269**	**$15,652**	
Fixed Fee if Applicable								**$ -**	
TOTAL CONTRACT COST	**$ 5,444.86**	**$ 5,466.04**	**$ 90,071.27**	**$ 11,838.94**	**$ 7,175.68**	**$64,271**	**$ 55,725.97**	**$119,997**	

NOTES: *Year 1 starts with the date of the contract and ends September 30th of the following year and is based on the federal fiscal year.
**** Exact cost of trips for project sites are difficult to estimate since project site locations are not identified yet. Based on extensive field work done by the PI on similar projects, the estimate given is reasonable and PI should be able to perform the work within the given budget.**

7. <u>Qualifications of Research Team:</u>

<u>Hani Titi, PhD, PE (Principal Investigator)</u>

Associate Professor in the Department of Civil Engineering and Mechanics at UW-Milwaukee and is a registered Professional Engineer. Dr. Titi has more than 20 years of experience in advanced experimental research and analysis, especially in problems related to pavement materials and geotechnical engineering. During his current position at UW-Milwaukee and previous position Louisiana Transportation Research Center and Louisiana Department of Transportation and Development, he conducted advanced research and served as PI and Co-PI for projects funded by different entities including: Wisconsin Highway Research Program (WHRP)/Wisconsin Department of Transportation, Minnesota Department of Transportation, Midwest Regional University Transportation Center, and Louisiana Department of Transportation and Development. The following are selected projects completed by Dr. Titi:

1. *Base Compaction Specification Feasibility Analysis*, Wisconsin Highway Research Program, Wisconsin Department of Transportation SPR # 0092-11-02. PI: Titi, Project Budget: $106,936. (Completed).
2. *Phase II Investigation of Testing Methods to Determine Long Term Durability of Various Types of Wisconsin Aggregate Resources*, Highway Research Program, Wisconsin Department of Transportation SPR # 0092-10-08. PI: Tabatabai, Project Budget: $59,991 (Completed)
3. *Characterization of Unbound Materials for ME Pavement Design of Marquette Interchange*, the Midwest Regional University Transportation Center through Marquette University, PI: Titi, Project Budget: $14,977. (Completed).
4. *The Effect of Minnesota Aggregates on Rapid Chloride Permeability Tests*. Minnesota Department of Transportation ($65,769). PI: Titi (Completed).
5. *Determination of Typical Resilient Modulus Values for Selected Soils Representative of the Soils Distributions of Wisconsin.* Wisconsin Department of Transportation, Wisconsin Highway Research Program, ($103,049). PI: Titi (Completed).

Dr. Titi is a member of TRB committees (AFS20, and AFS30), a member of NCHRP panel D2431, and the Secretary of the ASCE-Geo-Institute Pavement Engineering Committee. Dr. Titi is the author and co-author of more than 70 publications (journal, conference and research reports) in the area of geotechnical and pavement engineering.

<u>Habib Tabatabai, PhD, PE, SE, (Co- Principal Investigator)</u>

Dr. Tabatabai, P.E., S.E. will serve the program as Principal Investigator. He is an Associate Professor of Structural Engineering at the Department of Civil Engineering, University of Wisconsin-Milwaukee. Prior to joining UWM in July 1999, he was a Principal Structural Engineer with the Construction Technology Laboratories, Inc. (a subsidiary of Portland Cement Association) in Skokie, Illinois. Dr. Tabatabai worked at the CTL Structural Laboratory for approximately 10 years beginning in 1989.

He is currently Principal Investigator for the WHRP project No. 0092-0606, Evaluation of Methods of Rebar Protection, Spall Prevention, and Repair Techniques on Concrete Girders. He is also serving as PI on a National Center for Freight & Infrastructure Research & Education (CFIRE) project related to statistical evaluation of truck loads from the Weigh-in-Motion stations throughout Wisconsin. He also served as Principal Investigator for the WHRP project No. 0092-01-06, Rehabilitation Techniques for Concrete Bridges, and is currently serving as PI for a NCHRP Synthesis project 35-07, Inspection and Maintenance of Bridge Stay Cable Systems. He was Co-Investigator for the NCHRP Project 10-53, "Condition Evaluation of Prestressing Steel Strands in Concrete Bridges" as well as a FHWA study on evaluation of non-electrical rehabilitation methods for prestressed concrete. He was the Principal Investigator for a FHWA study on stay cable condition assessment and Co-Investigator for a FHWA study on jointless bridges. He served as Principal Investigator for a research project for the Nuclear Regulatory Commission to develop a system for detecting wire breaks in unbonded post-tensioning tendons. He has led several consulting projects involving investigations of structural failures, repair and rehabilitation of structures, corrosion evaluations, field instrumentation and load testing of bridges, etc. Habib Tabatabai is a licensed Structural Engineer (SE) and Professional Engineer (PE) in Illinois. He has published over 40 papers and has a US patent on a damper system for stay cables. He is an Associate Member of the Post-tensioning Institute (PTI) committee on cable-stayed bridges, and a member of the ASCE Committee 19. He received his Ph.D. in Civil Engineering (Structures) from the University of Florida in 1987. After graduation, Dr. Tabatabai worked as a bridge designer for the Structures Design Section of the Florida DOT for 2-1/2 years. His work included in-house design of new bridge structures, review of bridge plans and calculations done by consultants, preparation of repair plans, bridge evaluations, load ratings, computer analyses, and other work related to bridges.

Ahmed Faheem, Ph.D., (Co- Principal Investigator)

Dr. Faheem is an assistant professor at the University of Wisconsin Platteville. He earned his PhD. degree from the University of Wisconsin, Madison. Dr. Faheem has experience in managing and conducting scientific research studies for ten years. He has conducted many research projects sponsored by the Federal, and State governments as well as private industry. His research interests span through a wide range of Asphalt pavement related topics. Dr. Faheem published his work in national and international journals. He presented his work in many conferences and invited to speak in many events. Dr. Faheem is a member of a number of national and international committees, and a reviewer of prestigious scientific journals. He conducted many research studies on asphalt binder, mastic, and mixture performance, and modeling.

Dr. Faheem is experienced in flexible pavements material and construction. He is a member of the research team involved in the ongoing project NCHRP project 9-49A to evaluate the performance of warm mix asphalt (WMA) technologies with respect to long-term field performance. Work on this project involves real time monitoring of the construction of multiple test sections. This project focuses on documenting changes in construction practices for WMA, and conducting non-destructive testing for quality assurance. The test sections are then monitored for few years to evaluate the long term performance in light of the findings of the onsite monitoring and testing.

Scot Schwandt, P.E. (CO-PI)

Mr. Scot Schwandt is a registered Professional Engineer in the state of Wisconsin and a Project Manager for The Transtec Group. The Transtec Group is a nationally recognized pavement engineering firm with vast experience in pavement research, pavement construction innovation techniques and pavement engineering software development including ProVAL® and Veda®. Scot's career consists of over 25 years of Civil Engineering-Transportation work experience in several positions including: Executive Director & Director of Engineering for the Wisconsin Asphalt Pavement Association (WAPA), Pavement Structural Design/Pavement Management Engineer for WisDOT and Bridge Design Engineer for WisDOT. Scot has been very active participating on national asphalt pavement committees and has a vast asphalt pavement related professional networking resource.

Skills that Scot brings to this research team include; WisDOT database knowledge, WisDOT specification implementation practice, pavement management modeling experience, pavement design experience, FWD forensic engineering experience, and pavement construction management experience. Serving on WisDOT's WHRP Steering Committee, FLEX TOC, HTCP Steering Committee and HMA Tech Team, he is very knowledgeable of WisDOT specifications, construction practices and research direction and implementation. As a private consultant, Scot has assisted WisDOT with Implements of Husbandry (IoH) studies.

Academically Scot is currently working on finishing a Ph.D. in Construction Materials with Dr. Hussain Bahia at the University of Wisconsin-Madison.

Erol Tutumluer, Ph.D., Professor, University of Illinois Urbana-Champaign (Consultant)

Dr. Tutumluer has research interests and expertise in testing and modeling of pavement and railroad track geo-materials, i.e., base/ballast unbound aggregates; recycled aggregates and their unbound applications, shape, texture, angularity characterization of aggregates using video-imaging techniques, use of geosynthetics in pavements/railroad track, modeling of particulate media using discrete and finite element methods, artificial intelligence in the form of neural network modeling, mechanistic based pavement design, and nondestructive pavement evaluation. He has authored and co-authored over 140 technical papers in these areas.

Dr. Tutumluer was the recipient of the Transportation Research Board's (TRB's) Fred Burgraff award for Excellence in Transportation Research in 2000. He is an affiliate of the TRB; and has chaired its AFS50 (1) subcommittee on "Applications of Nontraditional Computing Tools Including Neural Nets." He serves on TRB committees AFP70, AFP30, AFS50, and AFD80. More recently, Dr. Tutumluer has been selected as the 2009 recipient of the TRB's Geology and Properties of Earth Materials Section Best Paper Award for my paper, "Use of Falling Weight Deflectometer Testing to Determine Relative Damage in Asphalt Pavement Unbound Aggregate Layers." The paper was nominated by AFP70 Mineral Aggregates Committee.
Dr. Tutumluer is currently the chair of the American Society of Civil Engineering (ASCE) Geo-Institute's Pavements Committee and the co-editor of five ASCE Geotechnical Special Publications on recent advances in transportation materials characterization, pavement engineering, and pavement mechanics and testing. He is also a member of the American Railway Engineering and Maintenance of Way Association (AREMA) Committee 1 on "Ballast."

8. Other Commitments of the Research Team:

Research Team Commitments		Percentage of Time	
Team Member	Role	Committed	Available
Hani Titi	PI	25%	25% to 50%
Habib Tabatabai	Co-PI	25%	25% to 50%
Ahmed Faheem	Co-PI	80%	20%
Scot Schwandt	Co-PI	80%	20%
Bill Niemi	Consultant	90%	10%
Erol Tutumluer	Consultant	80%	20%

9. Facilities and Information Services:

UWM Library:

The library has extensive collections of periodicals, literature, and related books. Materials that are not available in the UWM Library can be obtained through its Interlibrary Loan department. In addition, the PI has access to the information retrieval files of technical literature abstracts such as TRIS and ASCE engineering database.

Geotechnical & Pavement Engineering Laboratories:

The proposed research project will be conducted at the Geotechnical & Pavement Laboratory of the Department of Civil Engineering and Mechanics at UW-Milwaukee. The laboratory is equipped with the necessary instruments and tools to successfully accomplish the objective of the research project. The following is a description of the main equipment:

Servo-hydraulic Dynamic Materials Testing System

State of the art Instron FastTrack 8802 closed loop servo-hydraulic dynamic materials test system at UW-Milwaukee. The system utilizes 8800 Controller with four control channels of 19-bit resolution and data acquisition. A computer with FastTrack Console is the main user interface. This is a fully digital controlled system with adaptive control that allows continuous update of PID terms at 1 kHz, which automatically compensates for the specimen stiffness during repeated load testing. The loading frame capacity of the system is 250 kN (56 kip) with a series 3690 actuator that has a stroke of 150 mm (6 in.) and with a load capacity of 250 kN (56 kip). The system has two dynamic load cells 5 and 1 kN (1.1 and 0.22 kip) for measurement of the repeated applied load. The load cells include integral accelerometer to remove the effect of dynamic loading on the moving load cell. Triaxial cells with maximum sample diameter of 6 in. are also available.

Equipment for Measurement and Determination of Soil Properties:

These include the following: Dynamic repeated load and static triaxial test, grain size analysis shakers (sieve analysis), temperature-controlled hydrometer path, specific gravity determination equipment, Atterberg limits (plastic and liquid limit of soils), automatic soil compactor (Standard and Modified Proctor test), digital-controlled ovens, automated direct shear test system, automated soil consolidation system, vibratory table for determination of relative density of cohesionless soils, unconfined compression test system, drying ovens, etc.

References:

1. Barksdale, R. D. (1991). *The Aggregate Handbook*, National Stone Association, Washington, DC.
2. Saeed, A., Hall, J., and Barker, W. (2001). “Performance-Related Test of Aggregates for Use in Unbound Pavement Layers,” National Cooperative Highway Research Program (NCHRP) Report 453, Transportation Research Board, National Research Council, Washington, D.C.
3. Titi, H.H., and Rasoulian, M. (2002). “Evaluation of Flexible Pavement Failure Using Nondestructive Methods,” *Structural Materials Technology V*, The American Society for Nondestructive Testing, Cincinnati, OH, pp. 86-92.
4. Tabatabai, H., Titi, H., Lee, C.W., Qamhia, I., and Puerta Fella, G. (2013) “Investigation of Testing Methods to Determine Long-Term Durability of Wisconsin Aggregates,” *Research Report, Wisconsin Department of Transportation SPR # 0092-10-08,* Wisconsin Highway Research Program, Madison, WI, 104 p.
5. Titi, H.H., Tabatabai, H., Faheem, A., Bautista, E., Tutumluer, E., and Druckrey, A. (2012) “Base Compaction Specification Feasibility Analysis,” *Research Report, Wisconsin Department of Transportation SPR # 0092-11-02*, Wisconsin Highway Research Program, Madison, WI, 127 p.
6. Titi, H.H., and English, R. (2011) “Determination of Resilient Modulus Values for Typical Plastic Soils in Wisconsin,” *Research Report, Wisconsin Department of Transportation SPR # 0092-08-12*, Wisconsin Highway Research Program, Madison, WI, 193 p.
7. Titi and Matar (2013). “Evaluation of Resilient Modulus of Wisconsin Virgin Aggregate for MEPDG,” paper under preparation funded by CFIRE.

UNIVERSITY OF WISCONSIN
PLATTEVILLE
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

January 23rd 2014

Dr. Hani H. Titi,
Department of Civil Engineering and Mechanics
University of Wisconsin-Milwaukee
EMS 1139
3200 N. Cramer St.
P.O. Box 784
Milwaukee, WI 53201

Re: WHRP RFP, "Evaluation of the Long-Term Degradation and Strength Characteristics of In-situ Wisconsin Virgin Base Aggregates under Hot Mix Asphalt (HMA) Pavements"

Dear Dr. Titi:

This letter is to confirm my interest in collaborating on the subject WHRP research project.

I am prepared to assist you as Co-Pi in all stages of the project to ensure the project requirements are met.

I look forward to participating on this important project and offering my expertise.

Sincerely,

Ahmed Faheem,
University of Wisconsin-Platteville

137 Ottensman Hall | 608.342.7249 | Fax: 608.342.1566 | fatinfaheema@uwplatt.edu
1 University Plaza | Platteville WI 53818-3099 | www.uwplatt.edu

THE TRANSTEC GROUP
The World's Pavement Engineering Specialists

January23, 2014

Dr. Hani Titi
Department of Civil & Environmental Engineering
University of Wisconsin-Milwaukee
P.O. Box 784
Milwaukee, WI 53201

Re: WHRP RFP, "Evaluation of the Long-Term Degradation and Strength Characteristics of In-situ Wisconsin Virgin Base Aggregates under Hot Mix Asphalt (HMA) Pavements"

Dear Dr. Titi:

Please accept this as my letter of commitment to provide services related to the above referenced solicitation. I will be available immediately upon receiving notice that our team has been awarded the contract and will be committed to the project until it is completed.

I look forward to the opportunity to support UW-Milwaukee in this research effort.

Sincerely,

Scot M. Schwandt

Scot Schwandt, Project Manager
The Transtec Group, Inc.

6111 Balcones Drive, Austin, Texas 78731 .voice 512.451.6233 . fax 512.451.6234 . www.TheTranstecGroup.com
The World's Pavement Engineering Specialists.

BLOOM COMPANIES, LLC
Infrastructure Innovation and Ingenuity

January 24, 2014

Dr. Hani H. Titi,
Department of Civil Engineering and Mechanics University of Wisconsin-Milwaukee EMS 1139
3200 N. Cramer St.
P.O. Box 784
Milwaukee, WI 53201

Re: Support for WHRP Project- Evaluation of the Long-Term Degradation and Strength Characteristics of In-situ Wisconsin Virgin Base Aggregates under Hot Mix Asphalt (HMA) Pavements

Dear Dr. Titi,

This letter is to confirm my interest in collaborating on the subject WHRP research project.

I am prepared to assist you as a consultant on the project to ensure the project requirements are met.

I look forward to participating on this important project.

Sincerely,

William Niemi P.E.
Bloom Companies, LLC
Email: bniemi@bloomcos.com

5801 Research Park Blvd, Suite 410 · Madison, WI 53719
P: 608-575-2683 · F: 414-771-4490

UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

Erol Tutumluer, Professor
Paul F. Kent Endowed Faculty Scholar
Director of International Programs
Department of Civil and Environmental Engineering
1205 Newmark Civil Engineering Laboratory, MC-250
205 North Mathews Avenue
Urbana, IL 61801-2352

January 23, 2014

Hani H. Titi, Ph.D., P.E., M.ASCE
Associate Professor
Associate Director for Pavements at the Center for By-products Utilization (CBU)
Department of Civil Engineering and Mechanics
University of Wisconsin-Milwaukee; EMS 1139
3200 N. Cramer St., P.O. Box 784
Milwaukee, WI 53201

Subject: Support letter for WHRP Project – Evaluation of the Long-Term Degradation and Strength Characteristics of In-situ Wisconsin Virgin Base Aggregates under Hot Mix Asphalt (HMA) Pavements

Dear Dr. Titi:

Please accept this letter as my commitment to be a consultant in the proposed WHRP research project on Evaluation of the Long-Term Degradation and Strength Characteristics of In-situ Wisconsin Virgin Base Aggregates under HMA Pavements. I understand that I will work with you and your research team in the project to provide guidance and support with the technical activities for a successful completion of the individual research tasks.

Related to this research topic, I have been involved with several studies at the University of Illinois: (1) A full scale geogrid base-reinforced pavement test section pavement performance study in which base course material strength, stiffness and degradation characteristics were quantified in the field and documented in several publications; (2) Illinois DOT ICT R27-1 and R27-81 projects on characterization of Illinois aggregates for subgrade replacement and subbase, which investigated in the Phase I lab testing the effects of 3 different aggregate types and their properties on compaction, strength and deformation behavior and in the Phase II full-scale pavement test cells the performances of 6 different aggregate base materials using our ATLAS full-scale pavement test machine at our Advanced Testing Research and Engineering Laboratory (ATREL).

I am the author of the 2013 NCHRP Synthesis 445: Practices for Unbound Aggregate Pavement Layers which consolidated information on the state-of-the-art and state-of-the-practice of designing and constructing unbound aggregate pavement layers to potentially improve pavement performance and longevity. Furthermore, I am currently leading a research effort titled "Base Course Aggregate Testing and Rutting Model Calibration" to develop improved rutting models for unbound aggregate materials commonly used in the state of North Carolina for pavement base and subbase applications. Preliminary results from this research study have helped establish the research plan framework we proposed for the recently solicited NCHRP 01-53 study, titled, "Proposed Enhancements to Pavement ME Design: Improved Consideration of the Influence of Subgrade and Unbound Layers on Pavement Performance." The research findings from all these projects will available for the use of your research team.

I look forward to working with you on the Evaluation of the Long-Term Degradation and Strength Characteristics of In-situ Wisconsin Virgin Base Aggregates under HMA Pavements project.

Very truly yours,

Erol Tutumluer, PhD
Professor and Paul F. Kent Endowed Faculty Scholar

telephone 217-333-8637 • *fax* 217-333-1924 • *e-mail* tutumlue@illinois.edu